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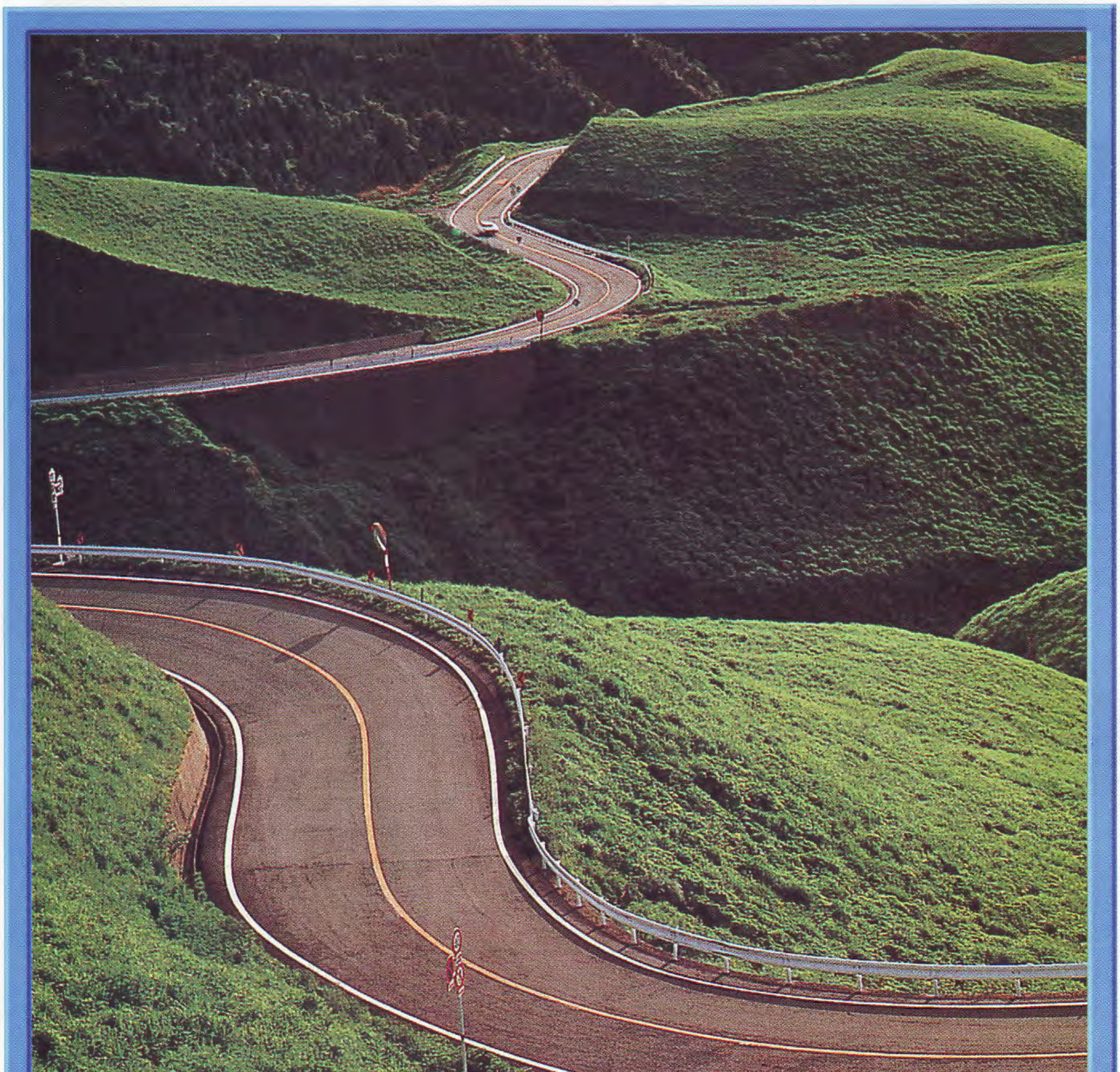

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Accelerated Dynamic Loading of Flexible Pavements at CAPTIF

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Bruce Steven is a Research Engineer at the Canterbury Accelerated Pavement Testing Indoor Facility (CAPTIF), located at Christchurch, New Zealand. He received a B.E. and M.E. from the University of Canterbury. Upon completion of his masters in 1992 he starting working at CAPTIF, implementing the day to day scientific requirements of projects.

Introduction

The New Zealand thickness design procedure for thin-surfaced, unbound granular flexible pavements is based on multi-layer linear elastic theory (AUSTROADS 1992; Transit New Zealand 1997). The procedure assumes that the surface thicknesses of less than 35 mm do not contribute to the structural capacity of the pavement and that the stresses are dissipated through the depth of the granular cover layers above the subgrade. The design theory presupposes that the primary mode of structural failure is permanent deformation in the subgrade, so the main criteria is to limit the vertical compressive strain in the subgrade to acceptable magnitudes (Transit New Zealand 1997).

At present, the maximum gross vehicle weight permitted on national highways is limited to 430 kN, and the maximum loads permitted for single, tandem, and triple axle groups are 80, 145 and 175 kN, respectively. One equivalent single axle load (esa) is defined as a 80 kN axle load on dual-tyres inflated to 700 kPa. Typically, the maximum design life would be in the order of 10 esa.

Because of the unique situation in New Zealand, with respect to both the road user charges incurred by heavy vehicles and the dependence on thin-surfaced flexible pavements, research has been undertaken to isolate the influence of various components of the vehicle/pavement interaction system, such as the static and dynamic components of vehicle loading, and the relative effects of vehicles, the environment and the pavement materials. Laboratory testing and computer analysis alone are inappropriate. Thus, trials utilising full-scale equipment and pavements are necessary, either in the field or in a test track under controlled conditions. Therefore, the first New Zealand accelerated loading facility was constructed in 1969 (Williman and Paterson 1971).

The first machine was used for a number of pavement research projects, and, in 1983, finally became unserviceable. An assessment of the need for a new, improved accelerated pavement loading facility identified four primary research priorities:

a) evaluating the performance of aggregates, such as marginal materials;

b) modified designs for surfacings, especially chip seals;

c) evaluating pavement design assumptions by collecting data describing the long-term performance of pavements; and,

d) investigating the relationship between vehicle loading conditions and the deterioration of pavements for a wide spectrum of pavement and loading characteristics.

Accelerated pavement testers have been constructed in a variety of configurations (OECD 1985). The facilities are generally classified as being either circular or linear test tracks. A circular test track in which full scale pavements could be constructed, and a loading apparatus capable of imposing realistic dynamic heavy vehicle loading, was selected because:

- the machine can be operated continuously without being interrupted for direction changes, thereby greatly increasing the rate of load cycling;
- after initial acceleration, the speed of the loading system can be kept constant for long periods of time or varied, depending on the requirements of specific projects;
- a circular track can be divided into a number of either annular rings or longitudinal segments, each containing a pavement with some unique characteristics, and all segments can be tested simultaneously under the same or varying loading conditions;
- the configuration of each loading assembly in a multi-armed machine, such as tyre types and pressures, axle numbers and weights, suspensions and loads, can be altered so that the same pavement can be tested under various loading conditions; and,
- the interaction of pavements and vehicle dynamics can be examined using a combination of unsprung and sprung masses possessing realistic damping characteristics.

Description of The Facility

The Canterbury Accelerated Pavement Testing Indoor Facility (CAPTIF) is housed in a hexagon-shaped building that is 26 m wide and 6 m high. An annular concrete tank, 1.5 m deep and 4 m wide, confines the bottom and sides of the track (Figure 1), enhancing the control of moisture contents in the subsurface systems and drainage. The track has a median diameter and circumference of 18.5 m and 58.1 m, respectively. Normal field construction and compaction equipment is used in the facility. The main feature of CAPTIF is the Simulated Loading And Vehicle Emulator (SLAVE).

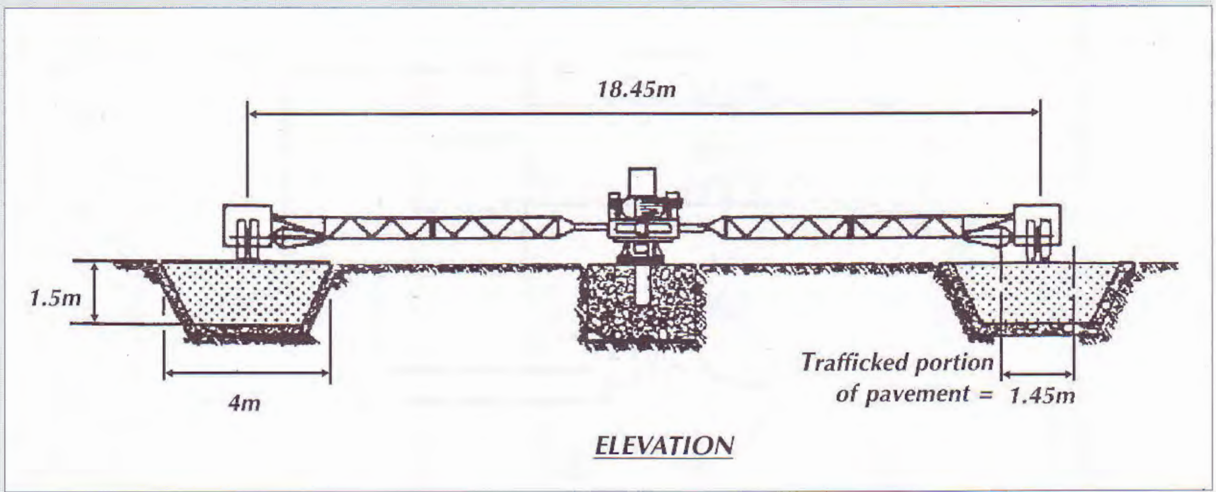

Figure 1: Elevation View of SLAVE and Cross-section of Pavement Tank

Simulated Loading And Vehicle Emulator

SLAVE was designed for the accelerated testing and evaluation of subgrades, pavements and surfacings by replicating the effect on the pavement of actual road traffic conditions. An elevation view of SLAVE is presented in Figure 1. A sliding frame within the central platform is moved horizontally a maximum of 1 m (from stop to stop) by two hydraulic rams; this radial movement produces multiple wheel paths. The base elevation can be altered by up to 150 mm, to maintain the dynamic balance of the machine if the pavement surface level changes due to rutting or an overlay being applied.

Each vehicle consists of the axle, which is driven by a hydraulic motor, a suspension, a frame, instrumentation, and standard wheel hubs and truck tires (Figure 2). The SLAVE vehicles can carry either single- or dual-tires; their loads can be adjusted to between 21 and 60 kN (42-120 kN axle loads) by adding or removing steel weights. The suspensions can be multi-leaf steel spring, a parabolic steel leaf spring or an air spring; each vehicle can carry the same or a different suspension for simultaneous testing. The speed can be any value between 4 and 50 km/h, and can be varied while running. The vehicles can be moved slowly, and positioned at any location on the track, using a hand-held, infrared remote control.

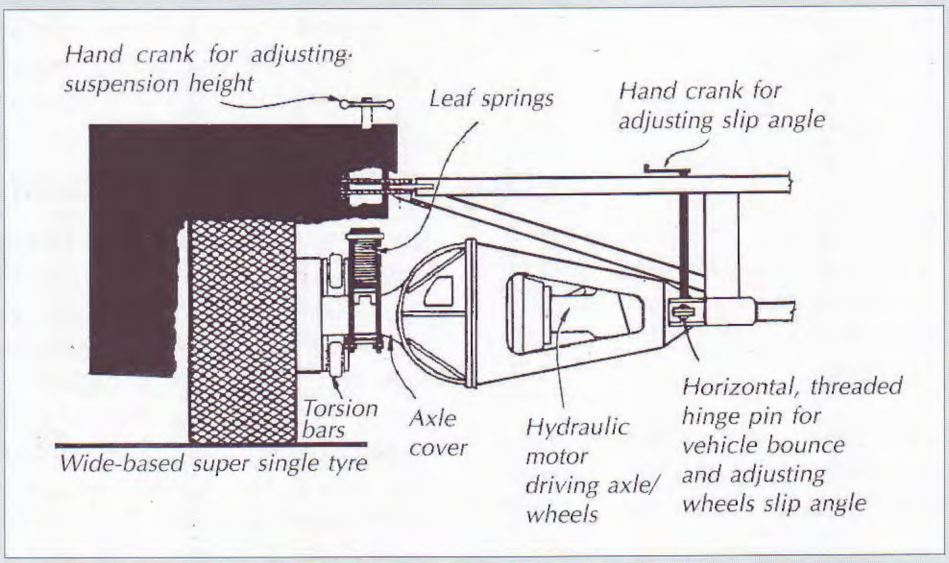

Figure 2: Cross-section of One SLAVE Vehicle

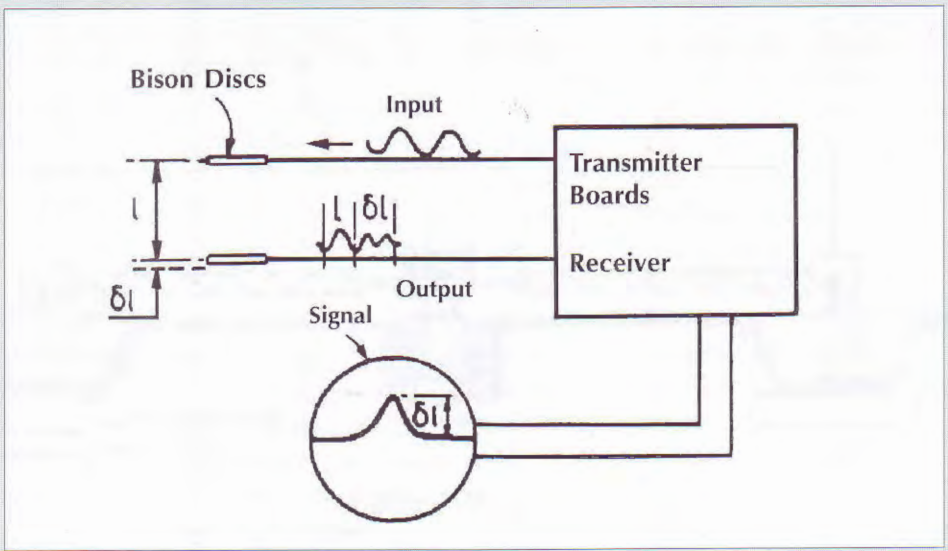

Figure 3: Principle of Bison Strain Sensors

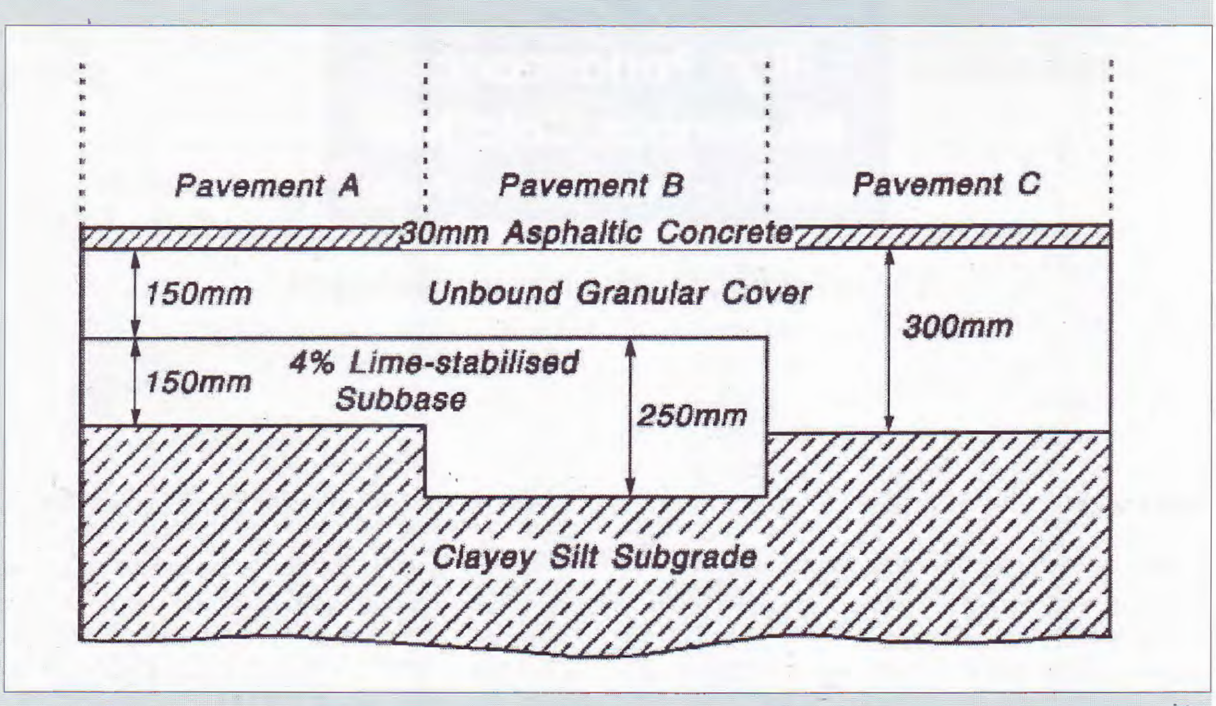

Figure 4: Cross-section of Lime Stabilised Subbase Pavements

SLAVE operations are directly controlled by its internal electronics. The external or on-shore computer is an IBM-compatible personal computer. Whenever a parameter is to be altered, the new command is sent by the external computer through a communications link under the track and a slip ring within the central pedestal. SLAVE and the computers can be safely left running without supervision.

Testing routines can be programmed in terms of loading cycles to be applied, travelling speeds, and tracking pattern of wheelpath positions, to name only a few. Any combination of these may be included in a programmed testing routine. Manual control can be imposed when desired, to override the current program. In addition to conventional hydraulic pressure, electrical current and motor over-load devices, the SLAVE electronics continually scans the safety monitors, and if a condition occurs which requires human inspection, brakes the vehicles to a stop.

High Performance Bituminous Cold Mix

Paving the Way for the Future

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Abstract

Development of high-performance cold mix (under trade name of ***IKRAMIX***), using specially formulated bituminous binder and locally available aggregate. ***IRKAMIX*** can be used as patching material to repair potholes in the asphalt pavements and spalls in concrete pavements. Three different grades of ***IKRAMIX*** have been developed for use on the lightly trafficked normal road, the heavily trafficked expressway and extremely heavily loaded airport pavement. The binder formulated for ***IKRAMIX*** has special properties that allows it to be used cold yet having high instant strength, unlike the normal penetration grade bitumen in the hot mix asphalt or other liquid bitumen in the conventional bituminous cold mix. The product is easy to apply, possess high instant bearing capacity which allows it be opened to traffic immediately after compaction, lasts as long as the original pavement life and is more friendly to the environment.

1.0 Introduction

Bituminous cold mix has traditionally been used by most road agencies to maintain their road network system. As the name implies, the mix is prepared cold using liquid bitumen as the binding agent to hold the aggregate particles together to form a composite material with a certain degree of visco-elastic properties. The application of cold mix has been limited to roadways and paved areas where the material has, to some extent, been proven to serve the intended purpose but does not have sufficient structural strength as compared to hot mix asphalt. Since the cold mix is normally manufactured using liquid bitumen in the forms of cut back or emulsion some 'setting time' is required for the liquid phase to evaporate before the compacted mix can be opened to traffic. Lately, the airport authorities have also been applying the cold mix as patching material to repair potholes in their asphalt pavements and spalls in concrete pavements. As a result of recent development and increasing demand for the material, efforts have been concentrated at Kumpulan IKRAM Sdn. Bhd. Research & Development Centre, to develop a specially formulated cold mix suitable for high performance application providing high instant strength.

The newly developed cold mix will be suitable for use as patching material for a wide range of applications i.e. from the lightly-trafficked normal road pavements to the heavy and extremely heavy trafficked expressway and airport pavements. To meet the requirements of different types of pavements, the high performance patching material was developed using specially formulated bitumen and gap-dense graded aggregate. The novelty is actually in the specially formulated binder, which has special properties that allows it to be used cold unlike the conventional penetration grade bitumen. While the penetration grade bitumen needs heat treatment (up to 160C) for mixing with aggregate to produce hot mix asphalt, and elevated temperature (above 100C) for effective compaction, the specially formulated binder may be mixed and applied cold. Extensive laboratory testing and formulation have resulted in a product which is easy to apply, posses high instant bearing capacity which allows it be opened to traffic immediately after compaction and last as long as the original pavement life. ***IKRAMIX*** is also more environmental friendly since it can be produced, packed and used cold. ***IKRAMIX*** can be packed in sealed container for marketing and may be stored for as long as 10-12 months. Laboratory evaluations and site trial applications have been conducted to actually assess the performance of ***IKRAMIX.*** Typical performance data in terms of stability, flow, void content, Marshall quotient, resilient modulus and rate of

rutting are presented for comparison with asphaltic concrete (ACW14) and a commercially available cold mix designated as 'Normal Cold Mix'. Advanced research is in progress at the Research & Development Centre to critically assess ***IKRAMIX*** behaviour under various applications and environmental conditions. Other cold mix formulations are also being developed as alternatives to the hot mix asphalt used in our road construction industry as an effort to produce a more environmentally friendly paving material for the future.

2.0 Development Cold Mix at Kumpulan IKRAM Sdn. Bhd.

Repair of potholes in asphalt pavements of spalls in concrete pavements is one of most commonly performed maintenance operations for most road and airport authorities. Potholes or spalls also hold the distinction of being the most aggravating pavement distress to the travelling public. Especially in airport, they are vital distresses to aircraft operations. Due to above reasons, the market demand for patching materials is very high.

Objective of this research is to develop a cold-mix patching material with a high performance for the above needs. It can be used satisfactory for patching on pavements with not only normal traffic but also heavy and extremely heavy traffic such as expressways and airport pavements. To meet requirements of different types of pavements, the high performance patching material developed will be a cold mix of a specially formulated bitumen and gap-dense graded aggregate with major properties: -

1. Convenient installation (no heating or priming)
2. Very high instant and long-term load-bearing capacity (even for Boeing 747)
3. Good adhesion to the existing pavement (even concrete pavements)
4. Immediate traffic access
5. Lasts as long as the original pavement
6. Long storage life (10-12 months)

The research project is conducted in three stages, laboratory research, field trial and evaluation, and study on production system. During the laboratory research stage, a series of in-house testing was conducted to design and analyse the formulation. In the field trial stage, the basic product was evaluated and modified where necessary, to achieve the required field performance. Different patching procedures were also tried at this stage. A practical full-scale production system will be developed in the final part of the study to produce the mix for commercialisation.

3.0 Laboratory Investigation

Extensive laboratory testing was carried out to characterise the properties of the binder. First, properties of a series of modified binder, prepared by double modification and double liquidation, were investigated based on the ASTM specifications tests for viscosity, penetration, softening point and anti-stripping requirements. Based on the test results, several potential modified binders were selected for the further research. At the moment, three grades of modified binder have been formulated. The applications of these binders are tailored towards the needs of three main categories of pavement loading described earlier i.e. normal roads, expressways and airports.

Gradations of aggregate used for the mixture were analysed. The standard methods outlined in the ASTM for test on density and void content were strictly followed to ensure reproducibility of test results. From these test results, several potential aggregate gradations were selected for future analysis.

Guidelines in the modified Marshall mix design procedures were referred to in the design of the bituminous cold mix. The cold mix prepared by combining selected modified binder and aggregates with selected gradations were evaluated in terms of Marshall stability and flow, void content and workability. A formula for the basic product was derived at the end of the process.

The cold mix prepared was also subjected to dynamic loading using MATTA Asphalt Testing System and Wheel-Tracking Test (WTT) to investigate its performance under the controlled laboratory condition. Results from such tests are useful indicators of material performance under service conditions. This also allows refinement to the formulation be made in order to achieve the desired mix properties. A summary of the tests conducted is presented in the proceeding section. Typical results obtained are tabulated in Table 1.

3.1 Resilient Modulus

The resilient modulus test was performed according to ASTM D 4123 at a temperature of

70°F (25°C). Testing was performed at three different frequencies 0.33, 0.50 and 1.00 Hz. In order to get testable samples, the cold mix materials were aged by heating them overnight at 275°F (135°C). Compacting them hot using 75 blows per side and allowing the compacted samples to cool in the molds prior to extrusion. The aging and compaction of these samples made the materials more representative of those that have been in place for several months under traffic.

3.2 Marshall Stability and Flow

The Marshall stability and flow test was performed according to ASTM D 1559. As with the resilient modulus samples, the Marshall samples were aged prior to compaction and testing, so the results are more representative of in-situ stability after several months of traffic.

3.3 Maximum and Bulk Specific Gravity

The maximum and bulk specific tests were performed according to ASTM D 2041 and ASTM D 2726, respectively. The value from these two were used to calculate the percent air voids of the mixes. The compactive effort used to prepare the bulk specific gravity test samples was the same as for the recent modules and Marshall sample preparations.

4.0 Wheel-Tracking Test

Wheel-Tracking Test (WTT) is a performance test, which is simulative in nature, for characterising permanent deformation (rutting) and evaluation of rut resistance in bituminous mixes. The test is carried out on compacted bituminous mix and therefore, enables direct measurement of the resistance to rutting of the cold mix developed to be investigated. The Wheel-Tracking Test is most useful in assessing the relative rutting resistance of different mixes under controlled environment and consequently provides ranking of the mixes in terms of rutting resistance. Table 3 represents typical values of WTT results conducted by Szatkowski (1979) at Transport and Road Research Laboratory (TRL), London.

4.1 Sample Preparation

Preparation of test specimen was carried out at Research & Development Centre using the procedure similar to that employed at the TRL. The specimens were compacted to the size of 407x137x90mm^3 in heavy steel-welded galvanised mould. Compaction of the specimen was by hand roller and electric vibrating hammer at a rate of 3.6 kg per 25mm width of specimen mould. This method of specimen compaction would to some extent, stimulate the actual rolling conditions in pavement construction.

4.2 Test Procedure and Result

The standard test was carried out at 45°C. The level arm of the wheel-tracking machine was loaded with weights, to give a total force on the wheel over a contact area equivalent to that of a heavy goods vehicle. The wheel was then passed over the slab (test specimen) at a frequency of 42 passes per minute with a total travel distance of 230mm. The vertical deformation (depth of track) was measured and plotted as a function time versus cycle. From this deformation, the mean rate of increase in track depth (mm/hr) was determined. Typical results are as shown in Table 2. The test was stopped when the material has tracked a depth of 10mm or after 10,000 cycles which ever is the lower. During the Wheel Tracking Test, the control sample (Asphaltic Concrete ACW14), ***IKRAMIX*** and 'Normal Cold Mix' were tested simultaneously. This allows a better control of test variables and will ensure reproducibility of test data. Graphical representations of the tabulated data are plotted in Figures 1 and 2.

5.0 Interpretation of Test Results

The rutting behaviour of the control sample, ***IKRAMIX*** and the normal cold mix can be analysed from the relationships of rut depth (mm) versus life cycle or time (hr). The overall performance of ***IKRAMIX*** (Figure 1), showed a very promising result compared to the control sample (asphaltic concrete ACW14) and the normal cold mix. The rut depth of ***IKRAMIX*** at 10000 cycles is only 4.7mm as compared to the control sample which measured up to 6.6mm and the normal cold mix 7.3mm. Analysis on the tracking rate measured in mm/hr at a controlled temperature of 45°C, showed that ***IKRAMIX*** gives a value of less than one (<1)mm/hr. Comparing the results obtained from this analysis to the earlier work conducted at the Transport & Road Research Laboratory in London by Szatkowski (1979), it is very clear that ***IKRAMIX*** has the potential to improve the rutting resistance and is suitable for application on "site with exceptionally heavy and chanalised traffic". Results from other evaluations as presented in Table 1, are also quite promising.

The Marshall stability for ***IKRAMIX*** is in the order of 1550kg with flow value of 3.8mm which gives a Marshall Quotient of 408kg/mm. This is a good indicator on the high durability of the mix and correlates well with the low rate or rutting as shown by the wheel-tracking test (WTT). A possible explanation for this exceptionally high value was the formulation in the binder, which allows it to be used cold yet permitting effective compaction of the gap-dense graded aggregate used in the ***IKRAMIX.***

6.0 Concluding Remarks

Advanced research is in progress at the Research & Development Centre to critically assess ***IKRAMIX*** behaviour under various applications and environmental conditions. Other cold mix formulations are also being developed as alternatives to the hot mix asphalt used in our road construction industry as an effort to produce a more environmentally friendly paving material for the future. Continuous research and development effort will be advocated towards the development of new internationally competitive products for the construction industry.

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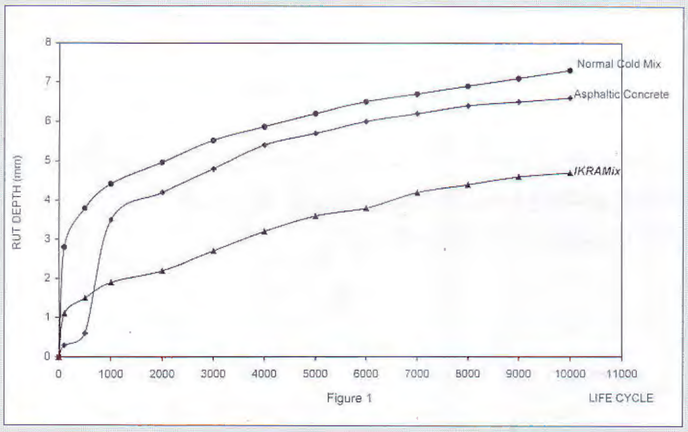

Figure 1

Wheel Tracking Test (WTT)

Relationship Between Rut Formation and Life Cycle

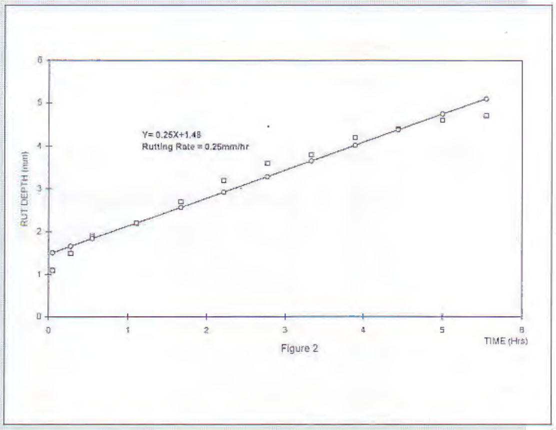

Figure 2

Wheel Tracking Test (WTT)

Tracking Rate for IKRAMix (mm/hr) at 45°C

PROPERTIES	*JKR Specification*	*Control Mix ACW 14*	**IKRAMIX**	*Normal Cold Mix*
Marshall Stability (kg)	Not less than 500	1050	1550	899
Flow (mm)	2 – 4	3.00	3.8	3.2
Air Void Content (%)	3 – 5	3.7	3.37	-
Marshall Quotient (kg/mm)	125 – 250	350	408	280
Resilient Modulus (MPa)	-	**2300**	**3302**	**1600**

Table 1 Results of Laboratory Evaluations on *IKRAMIX,* Normal Cold Mix And Control Mix (Asphaltic Concrete ACW 14)

LIFE			RUT (mm)	
Cycle	Time (hour)	Control Mix ACW 14	***IKRAMIX***	Normal Cold Mix
0	0	0.0	0.0	0.0
100	0.05	0.3	1.1	2.8
500	0.28	0.6	1.5	3.8
1000	0.55	3.5	1.9	4.2
2000	1.11	4.2	2.2	4.6
3000	1.67	4.8	2.7	4.9
4000	2.22	5.4	3.2	5.3
5000	2.77	5.7	3.6	6.2
6000	3.33	6.0	3.8	6.5
7000	3.89	6.2	4.2	6.7
8000	4.44	6.4	4.4	6.9
9000	5.00	6.5	4.6	7.1
10000	5.55	6.6	4.7	7.3

Table 2. Result of the Wheel Tracking Test on *IKRAMIX*, Normal Cold Mix and Control Mix (Asphaltic Concrete ACW 14)

	Minimum Requirement				
Traffic Intensity Commercial Veh/day/ lane	**Maximum Tracking Rate (mm/hr) at 45°C**	**Binder Content By**	**Fine Aggregate Quality**	**Minimum Ring & Ball Softening Point (°C)**	**Nearest Commercial Grade**
No significant Commercial Traffic	32	Recipe	Most natural sands conforming to BS594	43	70 pen
750	16	Recipe		47	50 pen
1500	8	Design	Stable Average Unstable	47 52 57	70 pen 50 pen 35 pen
3000	4	Design	Stable Average Unstable	52 57 62	50 pen 5 pen 3 HD
6000	2	Design	Stable Average Unstable	57 62 -	35 pen HD -
>6000	<2	Design	Stable Average Unstable	62 67 -	HD HD or Additive
Site with exceptionally heavy and chanalised traffic	<1	Design	Stable Average Unstable	Special Binders -	HD HD or Additive

Table 3. Characteristics of Low Stone Content Rolled Asphalt Wearing Course with the Stability Necessary to Give Rutting on Road of Less 1/2mm/year

(After Szatkowski, Transport & Road Research Laboratory, London 1979)

Drivers' Compliance with Posted Speed Limits On Urban and Rural Roads

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Abstract

The impact of driving at high speed on traffic accidents has been quantified. Speed studies have been carried out on 46 urban and 5 rural sites in order to address the problem of speeding. Evaluation of the posted speed limits has been scientifically conducted based on the 85th percentile method. The drivers' opinion about speeding has been clarified through a questionnaire. An interview of 400 drivers was carried out.

The results obtained indicated that speed related accidents constitute about 6% of the total accidents. The posted speed limits are lower than the 85th percentile speed by different values depending on road type and the posted speed limit. The models describing this relationship have been stated.

It was concluded that public authorities have over emphasised the effect of speeding on traffic safety. Postal speeds are respected on urban roads more than on rural. Police enforcement is the most effective way to control speed on roads. Drivers behaviour on roads is different from their believes.

Introduction

Speed is the rate of movement. It is the distance travelled by a vehicle in a unit of time. Speeding is the movement of a vehicle at a rate greater than a defined rate. This defined rate may be a posted speed limit or a limit that is accepted by 85% of the drivers (85th percentile speed). Citizens often use the word speed to mean speeding or driving in a rate greater than that posted on the highways word speed. Speeding is a relative term. What is more critical than speeding is "Unsafe Speed".

Complaints of speeding are a major concern for local traffic engineers and police department. These complaints are sometimes emotional and dominated by compassion and concern for local needs (1). However, speeding has two major disadvantages: traffic accidents and fuel consumption. The first is more noticeable and of greater interest for official and public authorities.

This study is a part of safety programme sponsored by the Traffic Institute and the Municipality of Greater Amman (M.G.A.). The request for the study came from the Central Traffic Committee due to repeated complaints of many public societies expressing unsatisfaction about high speeds on Jordanian roads.

The study investigates vehicles' speed on urban and rural highways and the accidents pretended to be a result of speeding. It consists of three parts having three objectives. Part 1 defines the amount of speed-related accidents and their results in order to estimate the magnitude and realty of the problem. Part 2 studies the compliance of drivers with the posted speed signs on both highway categories, in order to evaluate posted speed limits. And a supplementary part 3 discusses the drivers point of view about speeding in order to compare their believers with their behaviours.

Data Acquisition

Traffic police department is the authority that is responsible for speed control and enforcement. Statistics of traffic accidents were obtained from traffic police department's annual reports (2) to fulfil the need for the first part of the study.

A combined team of traffic engineers gathered urban and rural speed data needed for the second part of the study. The team included traffic engineers from the Traffic Institute and the M.G.A. Speed observations were taken at 46 urban and 5 rural locations. The urban sites were selected in the districts of M.G.A. where 35% of Jordan's population live. The city has 82% of the country's registered vehicles. Traffic accidents in the city count for 53% of those occur in the country (3). The selected sites represented the different speed limit signs posted in 4-lane divided streets. Speed limit sign locations of 50, 60, 70, 80, and 90 km/h in urban streets were under investigation. Rural sites were chosen along the 4-lane divided Amman-Irbid highway to represent the 60, 70, 80, 90, and 100 km/h speed limit signs. The reason for not considering signs of less than 50 km/h is that the speed in the streets having such signs is not free and also because these streets are normally consisting of 2 lanes. Spot speed measurements were taken during non-peak periods (between 0900 to 1130h) during June and August of 1997. The sample size at each site was determined to achieve 90% confidence level according the following equation (4)

$$N = \frac{S^2K^2(2+U)^2}{2E^2} \quad \text{.....................(1)}$$

Where: N= minimum sample size

S= estimate sample standard deviation km/h

K= number of standard deviations corresponding to the desired confidence level

E= permitted error in speed in the speed estimate

U= constant corresponding to the desired speed statistic

For the purpose of determining the 85th percentile speed; the following values were taken:

S=8; K=1.64 (90% confidence), E= ±4 for urban; and ±5 for rural; and U=1.04. Applying these values resulted in sample size = 50 for urban site and 32 for rural. However; these values were later (after data collection) proven to be correct except for S value for urban sites. The sample size for urban sites was reconsidered later and a number of 60 vehicles were decided. Thus a number of 60x46+32x5 = 2920 spot speeds were recorded. Laser radar mounted between trees or concealed on top of unmarked vehicle was used to measure the speed. It should be noted that differential speed limits for passenger cars and heavy vehicles are applied on Jordanian roads. Speed limit for passenger cars is always higher than that for other vehicles by 10 km/h. When spot speed for heavy vehicles was measured it was related to the appropriate posed speed and so forth for passenger cars. The number of heavy vehicles considered among the sample size was proportional to their percentage in total traffic.

The drivers' opinion, which consists the third part of the study, was clarified through a questionnaire. The binomial distribution was applied to determine the number of the sample size. The minimum number of respondents was determined by following equation (4):

$$N = \frac{pqK^2}{E^2} \quad \text{.......................................(2)}$$

Where: N = minimum number of responses

p = proportion of YES answers

q = proportion of NO answers

K = number of standard deviations corresponding to the desired level of confidence

E = permitted error in proportion estimate of a "YES-NO" question

For the purpose of this study; a conservative value of 0.5 for p and q; a value of 2.00 for K which corresponds to 95.5% confidence level, and an error tolerance E=±0.05 were considered. These values revealed a sample size N=400.

An interview of 400 drivers was carried out at the Vehicle and Drivers Licensing Department. This place was chosen because it is easier to find drivers in one place rather than stopping vehicles in streets and highways. The drivers answered the questions while they were in the queue to obtain their driving license or while they were waiting for their vehicles to be technically inspected. The drivers at this state had a suitable mood to answer questions because they were not in a hurry. Undistinguished police students wearing civilian

dress recorded the answers. The interviews were taken between the hours 9-11 AM; Saturday through Wednesday; during June and August 1997. A great care was taken to make sure that only the desired drivers were interviewed.

Analysis and Discussion

The obtained data were analysed according to their style and objective as follows:

Accidents Related to Speed

Driving at high speed contributes to increase in accident probability simply because of the physics of vehicles in motion as follow (5):

1 – When moving at higher speed, a car moves a longer distance during any fixed period of time that it takes for a driver to react;

The distance required for stopping a vehicle by braking increases with speed; and Crash severity increases disproportionately with speed at impact. The Relationship between fatality risk and change in velocity (Delta V) during collision has been shown to be exponentially to the fourth power (6)(7)(8). The problem of the speed-related accident is its severity due to the great shock, which may occur, particularly at high speed. A driver crashing at velocity of 80 km/h is twice as likely to be killed as one crashing at 60 km/h.

allow for a proper analysis of effect of speed on accidents because in accident forms, accidents that are attributed to "speeding" or "going too fast" are judged against the posted speed limit sign at the accident site. In a previous study (9), speed caused about 5.7% of traffic accidents in Jordan. Speed was ranked the third among the general causes (wrong overtaking 9.2% and close following 7.16%). However, it can be seen from Table 1 that speed had caused about 6% of the total traffic accidents which resulted in about 9% of the causalities, and 20% of the fatalities that have resulted from all traffic accidents in the country.

Evaluation of posted Speed limits

Methods used for setting speed limits include (4):

1. The "I" th percentile speed that value below which "I" percent and above which "100-I" percent of the spot speeds occur.
2. The pace, this is the speed range, usually 10 km/h in which more vehicles travel than any other range of speed.
3. The design speed that is highly dependent on the road geometry and attribute with high safety factors.

Setting speed limit based on the 85th percentile speed is world wide recommended (10). The

Year	Speed-Related Accident		Speed-Related Injuries		Speed-Related Fatalities	
	No.	% of Total	No.	% of Total	No.	% of Total
1994	1605	6.0	1059	8.5	88	19.9
1995	1869	6.5	1103	8.4	69	14.7
1996	2220	6.6	1494	9.7	114	20.6

Table 1. Statistics of Speed-Related Accidents

Recording the speed as the major contributing factor for traffic accidents conceals the truth about the underlying cause of these accidents. Such as aggressive driving, improper lane changing, and following too closely. Relating accidents to speed as a major cause is simple and does not require precise investigation like other mentioned causes. The negative reaction to speed is a translation of inefficient accident cause diagnoses which; in some times; enhanced by emotion.

Traffic police records through the years 1994-1996 were examined to highlight speed-related accidents. Table 1 shows summary of these records. Unfortunately these records does not

AASHTO policy (11) suggests using the 85th percentile speed for setting speed limits at or below 80 km/h and the 90th percentile for setting speed limits about 80 km/h. The 85th percentile speed was considered in this study for the following reasons (12):

1. The 85th percentile speed reflects a safe speed for site existing conditions as perceived by the majority of the motorists.
2. The probability of accidents is low for vehicle travelling below the 85th percentile speed.
3. The 85th percentile speed is self-enforcing; thus reducing police manpower required for speed enforcement.

Table 2 shows the average 85th percentile speeds and the average percentage of compliance with the posted speed for the selected sites on both road categories. It should be noted that the table does not contain the posted speed 50km/h for rural and the 100km/h for urban roads because they are not applicable.

Posted Speed km/h	85th Percentile Speed km/h		%Compliance	
	Urban	Rural	Urban	Rural
50	77	N.A	2	N.A
60	78	83	16	9
70	82	91	33	25
80	87	99	50	29
90	96	104	60	31
100	N.A	109	N.A	40

N.A = Not Applicable

Table 2. Compliance with the 85th Percentile Speed

Figures 1 and 2 show the above data in more illustrative manner. Table 2 and figure 1 indicate that the 85th percentile speed on rural roads is higher than that on urban roads for the same posted speed. In other words posted speeds are more indicative in urban areas than in rural.

The models describing this relationship are as follows:

For urban roads: Y= 0.65X + 45.2 .... (3)

For rural roads: Y= 0.47X + 51.1............. (4)

Where Y=85th percentile speed in km/h, and X= posted speed in km/h.

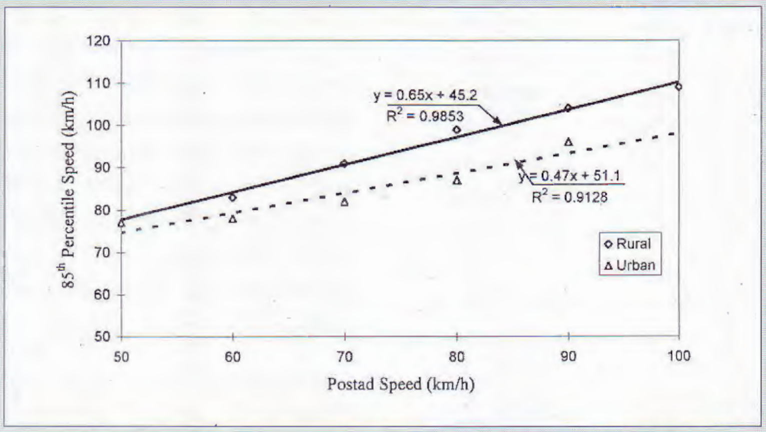

Figure 1 Relationship between 85th Percentile Speed and Posted Speed

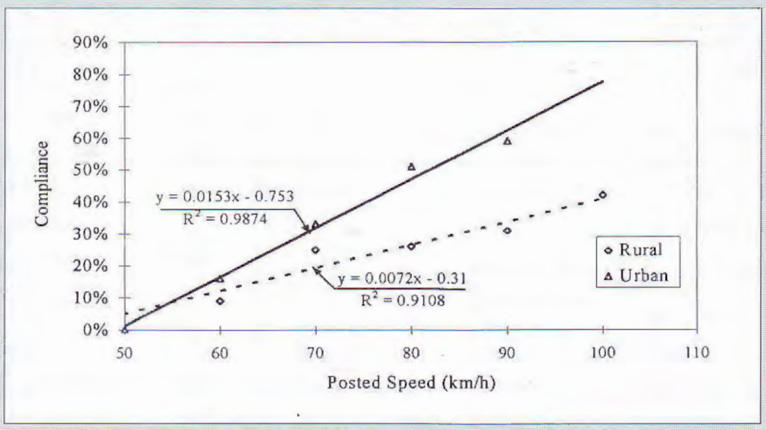

Figure 2 Compliance with Posted Speed

Figure 2 shows the degrees of drivers' respect for the speed limits posted in urban and rural roads represented as the percentage of compliance. This percentage is a measure of the drivers who drive at or below the indicated-posted speed. For example if the compliance % for a 70 km/h posted speed is 25%, that means only 25% of the drivers pass this zone at or below 70 km/h. The figure indicates that the posted speed is more respected at higher speeds rather than at low ones on both road types. This trend implies that high speed limits are more reasonable and satisfactory for the drivers. It also shows that the posted speed is more respected in urban areas than in rural. The models that describe the degree of compliance are as follows: -

For urban roads: $Y= 1.53\ X - 75.3$ .... (5)

For rural roads: $Y= 0.72\ X - 31$ .... (6)

Where: Y= percentage of compliance, X= posted speed in km/h.

The above analysis emphasised an inescapable fact about the way by which speed limits on Jordanian roads were decided. The fact is that these posted speeds have not been scientifically determined. They are in most cases arbitrary decided based on judgement and experience and not according to real speed studies. Besides that they are not consistence with conditions along the streets. The rationale behind this is the existence of a wide margin of safety, which is tolerated by a high percent of the drivers. One factor that seems to affect the probability of crash occurring is the speed of the vehicle in relation to the speed of all other vehicles travelling on the road at the time (13). The greater the discrepancy between a vehicle's speed and the average speed of other vehicles on the same section of the road, the more likely the vehicle is be involved in an accident (14).

The Drivers' Opinion

In speed debate all believes agree that driving at high speeds is dangerous. But it appears that drivers' believes change when they are at action. This phenomenon is shown is Table 3 which contains the result of the questionnaire made for this purpose. The respondents were asked first whether they drive fast or not. Those who acknowledged that they drive fast (400 driver) were interviewed. They were asked two questions of multiple answers. The first question deals with the reasons of speeding and has 18 choices. The first seven choices deal with the characteristics of the drivers. Choices 8-12 deal with road conditions. And choices 13-18 expose the effect of vehicle characteristics. The second question has only 5 choices and deals with remedies to reduce high speeds.

In response to the first question; most of the answers were logical. High percentage of the drivers (94%) acknowledged that they drive fast because police enforcement is not efficient. Other reasons for speeding have obtained different percentages of the respondents as shown in the table. The drivers were asked to explain their behaviour relative to road surface. Above 90% of the respondents are encouraged to drive fast if the road is in good conditions. As much as 68% of the drivers respond to the pressure of passengers and increase their speeds. Factors related to the vehicle indicated that driving high standard, new, and well-equipped vehicle will enhance speeding. About half of the respondents drive at high speed when they drive other's vehicles. Only 31% acknowledged that they drive fast when they operate their own vehicles.

In response to the second question, the interview showed that 53% of sample think that increasing police patrols is the best method to calm speeds. Other remedies have different degrees of importance as shown in the answers 19-23 in the table.

Q1 Do you drive fast because: *A Factors Related to Human (Drivers)*	**YES** %	**NO** %
1. Of efficient police enforcement	94	6
2. You used to drive so	84	16
3. You are influenced by speed environment	74	26
4. You are in happy mood	64	36
5. You are in sad mood	57	43
6. You want to arrive faster	45	55
7. You sometimes do not estimate the risk	40	60

B Factors Related to Vehicles	YES %	NO %
8. You drive high standard vehicle (full option)	96	4
9. You drive new vehicle	83	17
10. You drive vehicle with high safety equipment	82	18
11. You drive others' (employer) vehicle	51	49
12. You drive you own vehicle	31	69
C Factors Related to Road and Environment		
13. Of absence of police patrol	98	2
14. Of good road geometry and smooth surface	95	5
15. Of absence of speed limit post signs	90	10
16. Of high level of service (low traffic capacity)	90	10
17. Of good weather conditions	84	16
18. Of passengers demand to speeding	68	32
Q2 Which of the following is the most effective measure in reducing speeding:	Percentage	
19. Increase of police patrol	53%	
20. Increase of traffic education	25%	
21. Increase of violations' fines and penalties	8%	
22. Installing traffic calming measures	9%	
23. Improving road warning and speed limit signs	5%	
Total	**100%**	

Table 3. The Drivers' Opinion

Conclusions and Recommendations

Speed studies have been carried out on urban and rural highways in order to address the problem of speeding. The impact of driving at high speed on traffic accidents has been quantified. Evaluation of the posted speed limits has been scientifically conducted. The drivers' opinions have clarified. The following conclusions could be drawn from the study:

1. The impact of speeding on traffic accidents is publicly exaggerated.
2. Posted speed limits are arbitrary decided based on experience. They are lower than the 85th percentile speeds. This provides a wide margin of safety that is tolerated by drivers. A low-posted speed limit on a highway with good geometric conditions may result in a wide range of speeds, which in turn lead to an increase in accident potential.
3. Due to their arbitrarily setting, posted speed limits are not respected in general, but they are obeyed in urban roads more than in rural, and at high speeds more than at low speeds.
4. Drivers' actions during driving do not match with their beliefs.
5. Increasing the efficiency of police enforcement is the most effective method to control speeding.

In order to minimise the burden of speeding, it is recommended that speed limits be reconsidered. The 85th percentile method is advised. This will reduce the gap between posted and practicable speeds. A table of the 85th percentile speed for the sites under investigation was given to the Central Traffic Committee and Municipality of Greater Amman for implementation. It is recommended also to improve police enforcement procedures. This is the most effective tool to control speed. Use of demerit point system is a valid option.

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